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STATUS OF US EPA's SLUDGE INCINERATOR REGULATIONS

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Status of US EPA's Sludge Incinerator Regulations

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ABSTRACT

This paper describes a potential regulatory approach that the U.S. EPA could use for controlling sewage sludge incinerators. This approach utilizes a most exposed individual risk assessment to ensure that sludge incineration air emissions will not cause an unacceptable health risk. An incinerator facility can demonstrate compliance using a three tiered system which proceeds from a simple worst case calculation to a more resource intensive site-specific demonstration. A key part of the tiering system is development of an accurate and reliable emissions data base for U.S. sludge incinerators which can be used to develop reasonable worst case emission control factors. The results of testing to date are discussed in this paper.

INTRODUCTION

In the United States, the quantity of municipal sludge produced annually has almost doubled since 1972 when the U.S. Congress enacted the Clean Water Act (Public Law 92-500) which imposed uniform minimum treatment requirements for municipal wastewater. Municipalities currently generate approximately 7.6 million dry metric tons of wastewater sludge per year or approximately 29 kilograms per person per year. Approximately 20 percent (1.5 million dry tons per year) of this wastewater sludge is managed by incineration processes.

Since 1985, the US EPA's Office of Water has been developing the technical basis for the promulgation of Federal Regulations for the major sewage sludge treatment and disposal methods. Work to date has focused on incineration, land application, landfilling and ocean disposal.

INCINERATOR REGULATORY APPROACH

The Agency is evaluating a risk assessment methodology to develop the standards for sludge incineration. The risk assessment approach has to date focused on the pathway of air emissions from incineration and their health impact on humans by inhalation. The Agency has also looked at the potential health impacts of incinerator ash and wet scrubbing effluent disposal but found these to be adequately controlled by existing practices. The pathway for ash disposal was eliminated from consideration because the ash is adequately controlled under the Resource Conservation and Recovery Act (RCRA). The scrubber effluent pathway was eliminated from consideration since scrubber water is almost always recycled into the waste water treatment plant and is treated.

The deposition of incinerator emissions, mainly particulates, is considered a potential pathway of concern, but present methodologies to evaluate deposition and its impact on the environment and human health has not been fully developed. EPA is developing a risk assessment methodology to evaluate the risk of emission sources from this pathway but it has not been applied to sludge incinerator emission as of this writing. EPA will be evaluating deposition impacts in the future as the models are refined. For the interim period, the assumption that particles behave as gases is used in the air dispersion calculations.

MOST EXPOSED INDIVIDUAL (MEI)

The proposed regulatory approach is based on the risk of exposure of the most exposed individual (MEI). The MEI is an individual (or individuals) which is assumed to reside at the point of maximum ground level concentration of the emissions from the individual incinerator facility outside the property fence line.

PARTICLE SIZE DISTRIBUTION

This refers to the size of the particulates emitted from the incinerator. Since EPA currently has very little data on particle size distributions from sludge incinerators, it is assumed that 100% of the inhaled particulate enters and is retained in the upper and lower respiratory tract. Any clearance of particulates from the upper respiratory tract results in particle ingestion.

SLUDGE POLLUTANTS TO BE REGULATED

During 1985, EPA identified the pollutants in sludge which can potentially cause health risks. A series of environmental profiles, which were essentially mini-risk assessments, screened a list of 42 pollutants for health impacts. For the inhalation pathway, a total of 17 sludge pollutants were identified as shown in the following list:

Incineration Pollutants of Conern

Aldrin	Chromium
Arsenic	Dieldrin
Benzo(a)pyrene	Lead
Beryllium	Mercury
Bis (2-ethylhexyl)phthalate	Nickel
Cadmium	PCBs
Carbon Tetrachloride	Toxaphene
Chlordane	Vinyl Chloride
Chloroform	

Using the risk methodology developed for the inhalation pathway and EPA approved air dispersion models, EPA determined that the 17 pollutants could cause significant health impacts if any or all of the following conditions exist at a sludge incinerator site:

- Significant concentrations of pollutants in sludge

- High sludge burning capacity
- Short stacks
- Low organic destruction efficiencies
- Low scrubber particulate removal efficiencies
- High metals emissions related to high incinerator operating temperatures

STANDARDS FOR THE INCINERATION OF SEWAGE SLUDGE

EPA's potential approach for regulatingsewage sludge incinerators is based on ensuring that resulting ambient air concentrations of 17 pollutants emitted from sludge incinerators would be below human health criteria. The ambient air concentrations are expressed as an annual average. The annual average is used since all but two of the pollutants of concern are carcinogens through inhalation and therefore, evaluated as pollutants causing toxic impacts from long term low level exposure. Therefore, EPA is evaluating the effects of chronic exposure rather than short term acute human health exposure. These concentrations are identified as Reference Air Concentrations (RACs).

In the process of setting the values of the various RACs, the Agency evaluated a variety of risk levels to the MEI ranging from 1×10^{-4} to 1×10^{-7}. At this time, the Agency has not decided what MEI risk level should be used in this potential approach to establish regulatory standards for any of the sludge disposal options including incineration.

For illustrative purposes only, a table of RAC values is presented below based on a risk level of 1×10^{-5} for each of the carcinogenic pollutants. Beryllium, mercury and lead are exceptions to the 1×10^{-5} risk level determination. Beryllium and mercury emissions are currently regulated under NESHAPS air standards. For lead, the RAC value was obtained by dividing the current NAAQS standard for lead of 1.5 ug/m³ by a factor of 4.

These values are set independently of any background concentrations and represent the increase in ambient air levels allowed to be contributed solely by sludge incinerators. The RACs calculated at a 1×10^{-5} risk level are as follows:

Pollutant	RACs (ug/m³)
Aldrin	0.0022
Arsenic	0.0023
Benzo(a)pyrene	0.0057
Beryllium	—
Cadmium	0.0057
Carbon Tetrachloride	0.27
Chlordane	0.090
Chloroform	0.43
Chromium	0.027
Dieldrin	0.0018
Lead	—
Mercury	0.38
Nickel	0.033
PCBs	0.0046
Toxaphene	0.031
Vinyl Chloride	1.4

A RAC for mercury and beryllium is not presented in the table above. These values are not needed to determine compliance because the NESHAPs for both mercury and beryllium emissions from sludge incinerators are stated as an emission rate in terms of g/24 hours. In evaluating the risks of mercury and beryllium emission from sludge incineration the Agency confirmed the emission rates developed earlier in the NESHAPs are adequate to protect public health.

Both nickel and chromium emissions from sludge incinerators present a specific problem in establishing a risk based RAC. In establishing the proposed RAC values, EPA has assumed that 100 percent of the emission of chromium and nickel are emitted in their most toxic form, hexavalent chromium and nickel subsulfide respectively.

Chromium can be emitted in either the carcinogenic, hexavalent state (Cr^{+6}) or in the non-carcinogenic relatively nontoxic trivalent state (Cr^{+3}). Trivalent chromium compounds have not been shown to be carcinogenic and trivalent chromium toxicity is prevalent only at levels higher than those levels normally found in sewage sludge or in sludge incinerator emissions. Although the hexavalent state could be expected to result from combustion because it represents the more oxidized state, some investigators speculate that most of the chromium is likely to be emitted in the trivalent states given that the hexavalent state is highly reactive.

Although preliminary investigations indicate that 90 percent to 99 percent of chromium emissions from combustion sources may be in the trivalent state, it appearss that hexavalent chromium can be emitted.

If EPA finds that the Cr^{+6} to total chromium ratio emitted in 10 percent Cr^{+6}, 1 percent Cr^{+6} or even 10 ppm Cr^{+6}, then the RAC, for the 1×10^{-5} risk level would potentially be:

	Chromium
Percent Cr^{+6}	RAC (ug/m³)
10	0.009
1	0.09
1×10^{-3}	90.0

Similarly, the Agency has ongoing studies on the health effects of nickel compounds emitted from combustion sources. These studies will evaluate a number of nickel compounds and their health effects. Until those studies provide otherwise, the Agency believes it should make the assumption that all emitted chromium and nickel compounds cause the health effects of the highly carcinogenic hexavalent chromium and nickel subsulfide.

It is important to re-emphasize that as of this writing, EPA has not decided on the risk levels for carcinogens for any of the sludge disposal options. The above criteria are presented for illustrative purposes only.

DEMONSTRATING COMPLIANCE WITH THE RAC

The requirements for EPA's potential approach are based on the owner/operator determining that the concentrations of the 17 pollutants in the sludge are such that the emissions from the incinerator(s) will not cause ambient ground level concentrations of the pollutants around the facility to exceed the RAC value. The owner/operator may demonstrate compliance with the RACs by one of three ways, depending on the concentration of the 17 pollutants in the sewage sludge. The potential approach will lay out the ways in which the owner/operator may demonstrate compliance in three successive more stringent tiers.

The basic equation for determining compliance is as follows:

$$FR_i = \frac{RAC_i \times 86{,}400}{DF \times (1\text{-}CE_i)} \qquad (1)$$

where

FR_i = allowable feed rate of sludge pollutant i (g/day)
RAC_i = Reference Air Concentration for pollutant i, (ug/m³)
DF = Dispersion Factor, (ug/m³/g/s)
CE_i = Overall system control efficiency, (dimensionless)

The two variables, DF and CE_i are determined for the facility and are combined in equation one with the RACs for each of the 15 pollutants being regulated. The resulting set of 15 allowable feed rate values are then compared with the facilities actual pollutant feed rate calculated from sludge analytical results and sludge incinerator feed rates.

TIERING SYSTEM

To expedite the permitting of facilities, the Agency has devised a three tier approach which will simplify the demonstration of compliance. The three tiers in essence define how the values of the dispersion factor (DF) and the pollutant control efficiencies (CE_i) are obtained.

TIER I

In Tier I the owner/operator obtains credit for the height of his stack in determining the maximum allowable sludge concentration. A correlation of incinerator stack heights versus dispersion factors calculated from the ISCLT air dispersion model is used. This correlation is based on a sensitivity analysis of sludge incinerator air dispersion characteristics using the ISCLT model. The sensitivity analysis results revealed that the most significant variable that impacts the dispersion of pollutants is the height of the exhaust stack. The other variables entered into the ISCLT model, such as stack gas temperature, stack gas velocity and meteorological data have significantly less impact on the dispersion of pollutants than does the stack height. Thus, EPA developed a reasonable worst case correlation of stack height versus the dispersion factor. The equation is shown below:

$$DF = \exp^{[4.424-0.0778(SH)]} \quad (2)$$

where:

DF = Dispersion factor, ($ug/m^3/g/s$)
SH = Stack height, m

For Tier I, the control efficiency (CE_i) for each pollutant is taken from a table of reasonable worse case control efficiencies. These worse case control efficiencies were developed from a statistical analysis of a series of sludge incinerator tests. Thus, Tier I allows the calculation of reasonable worse case pollutant feed rates using only the RACs specified by EPA, control efficiencies specified by EPA and the stack height at the facility. This approach will allow a significant number of U.S. sludge incinerators to meet the new regulations with a minimum of effort and expense.

TIER II

An evaluation under Tier II is required if a facility can not demonstrate compliance under Tier I for all of the pollutants of concern. The Tier II assessment requires site specific air modelling to determine the value of DF and retains the reasonable worst case pollutant control efficiencies used in Tier I.

The detailed air dispersion analysis must be performed to establish the site specific dispersion characteristics and establish the relationship between stack emission rates and the maximum annual ground level concentration around the facility. Modeling should be done in accord with EPA's *Guidelines for Air Quality Modeling*. After the air modeling is completed, the facility can then calculate the allowable pollutant feed rates (FR_i) using equation (1).

Tier III

If an evaluation under Tier II as described above, determines that one or more sludge pollutants fails the allowable pollutant feed rate (FR_i), then an evaluation under Tier III must be conducted. The Tier III assessment requires actual measurement of the control efficiency of the incinerator system by means of an emissions test. The emission tests are required to obtain a site-specific assessment of the efficiencies of the incinerator and air pollutant control devices for any of the pollutants of concern that fail Tier II. It should be noted that a facility need not test for all of the 17 pollutants if the owner/operator has clearly demonstrated that the allowable pollutant feed rates are not violated under either Tier I or Tier II.

Any emissions tests must be structured to provide data to determine the incineration system's ability to control pollutants in the sludge. These test results are used to calculate the system's overall control and destruction efficiency. These site specific efficiencies are used to replace the reasonable worst case control efficiencies CE_i used in the Tier I and II calculation. Since the reasonable worst case control efficiencies represent the lowest end of anticipated performance, actual control efficiencies measured during the test would be expected to be higher, yielding higher allowable pollutant feed rates.

The objectives of a performance test for a sewage sludge incinerator are two fold. First, the overall control efficiency of the incinerator and air pollution control (APC) system must be determined for any of the pollutants failing Tier II. The overall incinerator and APC efficiency directly relates the pollutant level in the sludge to the stack emissions. The second objective of the performance test is to obtain data during the test which can be used to specify the operating ranges to be placed as conditions in the facility's permit. These permit conditions will provide reasonable assurance that the incinerator is operating within the range of parameters which yielded the pollutant control efficiencies measured and used in the Tier III determination.

EPA is preparing guidance for the conducting of sludge incinerator tests. The guidance will specify sampling methods, sampling frequencies and test methods for the 17 pollutants. This guidance will be available prior to the final promulgation of the incinerator rules. Prior to the publication of the incinerator test guidance, any test plans for sludge incinerators prepared to comply with this regulation should be reviewed by the permitting official prior to the test.

Sludge incineration facilities that cannot control emissions to levels low enough to meet the acceptable annual air quality concentrations under Tier III have several options as to corrective actions. One option is to cease sludge combustion and redirect sludge to another disposal option which will be in compliance with EPA's rules. However, few facilities are expected to close since incineration facilities are built at great expense and were undoubtedly chosen after other disposal options were investigated. Therefore, EPA expects that nearly all incineration facilities currently operating which fail to meet one or more RACs, will attempt to reduce emission rates by some other action such as installing upgraded air pollution control equipment to remove additional quantities of pollutants. This upgrading could, for instance, be a replacement of a low pressure drop wet scrubbing system, with a high pressure drop venturi wet scrubber. Other facilities may elect to install afterburners to reduce emissions of organic sludge pollutants which result in exceedances of the RACs. The replacement of multiple hearth furnaces with fluidized bed incinerators is a potential option for meeting the RACS for organics. Others may need to upgrade to fabric filters (bag houses) or electrostatic precipitators (wet or dry). The selection of the individual upgrade will be decided by the individual facility owner/operator.

A third option is to intensify efforts to pretreat industrial influent before entry into the POTW to reduce the levels of pollutants in sludge. A final option for an incinerator owner/operator is to reduce the rate at which the sludge is incinerated to meet the pollutant mass feed rate that meets the RAC.

DETERMINING TIER I AND TIER II EMISSIONS CONTROL

An integral part of the tiered approach to demonstrating compliance is to have a realistic data base on the ability of sludge incinerators to control the emissions of the sludge pollutants identified in the proposed regulation. A reliable data base on emissions control will allow EPA to identify and specify realistic worst case control efficiencies needed to complete the Tier I and Tier II analysis.

As part of the early regulatory development, the EPA data base and general literature were searched for sewage sludge incinerator test results. A number of emissions tests were identified dating, back to 1972. This data was complied and evaluated as to its usefulness for development of regulations. The "existing" test results were focused almost exclusively on the emission of particulates and metal. Practically no data exists on the emissions of organic compounds.

A statistical summary of the "existing" data on the metals of concern is presented in Table I.

As a technique for developing the reasonable worst case control efficiencies for the metals of concern, the 10th percentile values were calculated as shown in Table I. However, due to wide ranges in the control efficiencies of some of the metals and the complete lack of data on organic control efficiencies, EPA conducted a series of sewage sludge incinerator tests in 1987.

The facilities tested included three multiple hearth furnaces and one fluidized bed furnace. All four facilities are equipped with wet scrubber air pollution control systems. The test program was designed to determine the following:

- The actual metals emissions and the metals control efficiencies of the incinerator and air pollution control systems.
- The destruction efficiencies for organics and the control of organic emissions by air pollution control systems.
- The formation of products of incomplete combustion (PICs) in the furnace combustion zone and their emission rates through the air pollution control system.
- Particle size distribution before and after the air pollution control system.
- The valence state of chromium emissions.
- The concentrations of organics compounds and metals in the scrubber water and ash effluents.
- The relationship of furnace operating conditions such as temperature, excess combustion air rate, and wet scrubber pressure drop to the amount of pollutants emitted.
- Variation in emission levels of pollutants during non-steady state conditions (start-up and shut-down).

The results of the four tests have been submitted to EPA. The Agency is in the process of completing an evaluating of the data collected. Tables II and III show the overall destruction and removal efficiencies for the pollutants detected in the four incinerator tests. A number of negative removal efficiencies for organic emissions are shown in table II and III. These compounds appear to be products of incomplete combustion (PICs) that are formed in the incinerator combustion zone. As of this writing, EPA has not reached a decision on the emission control values to be used in the Tier I and Tier II compliance calculations. The following paper presents in more detail the results of the four incinerator tests.

Table I
Summary of Existing Data Base For Metals

Contaminant	Number of Observations	Minimum	Mean	Maximum	10th Percentile
Arsenic	4	98.74	99.15	99.89	98.74
Cadmium	20	40.25	90.03	99.88	53.55
Lead	20	34.22	93.12	99.87	67.44
Nickel	15	83.40	98.28	99.88	95.84
Chromium	20	88.82	99.12	99.89	98.44

Table II
Removal and Destruction Efficiencies for 17 Pollutants in Proposal

	Site 1	Site 2	Site 3	Site 4	10th Percent
Incinerator Type	MHF	MHF	FBF	MHF	
Metals					
Arsenic	93.4-94.3	94.89-95.05	99.83-99.99	99.29-99.50	94.1
Cadmium	81.0-77.0	75.0-85.0	99.96-99.50	21.1-92.30	81.0
Chromium	99.79-99.99	97.23-99.00	99.28-99.99	83.35-94.31	92.7
Lead	57.0-99.0	95.00-97.30	99.87-99.99	85.47-98.00	57.0
Nickel	97.0-99.9	93.83-99.38	99.87-99.91	99.81-99.84	95.0
Organics					
Aldrin	ND	ND	ND	ND	
Benzo(a)pyrene	ND	ND	ND	ND	
Bis(2-ethylhexyl) phthalate	95.7(1)	ND	ND	ND	
CCl4	98.0***	99.5	79.1	ND	
Chlordane	ND	ND	ND	ND	
Chloroform	-96.0	-39.6***	+41	-527.5	
Dieldrin	ND	ND	ND	ND	
PCBs	ND	ND	ND	ND	
Toxaphene	ND	ND	ND	ND	
Vinyl chloride	+426	-112***	ND	ND	

NOTES:

(1) The pollutant was detected in the stack emissions, but not the sludge. Efficiency calculated using analytical detection limit in sludge.

Negative efficiency values indicate more pollutant was emitted in stack than was detected in sludge, which is interpreted that part of the emissions are PICs.

Table III
Organics Identified in Sludge Incinerator Testing and Not In Proposed Sludge Regulations

Compounds	DE Range Hi	DE Range Low
Semivolatiles		
1,2-Dichlorobenzene	97.3	94.2***
1,3-Dichlorobenzene	99.7	67.5***
1,4-Dichlorobenzene	95.7	87.4***
2-Nitrophenol	97.2	ND
Phenol	81.7	ND
Naphthalene	90.9	ND
Volatiles		
Acrylonitrile	-1.9***	-349.0***
Benzene	25.3***	-1314.0***
Chlorobenzene	99.8	23.0
1,2-Dichloroethane	97.0	ND
Trans 1,1-Dichloroethene	99.4	76.0***
Ethylbenzene	99.3	6.0***
Methylene Chloride	98.6	-145.0(1)
Tetrachloroethene	98.6	-175.0***
Toluene	99.7	-256.0***
1,1,1-Trichloroethane	99.6	70.0***
Trichloroethene	97.9	-67.0

Notes:

(1) The pollutant was detected in the stack, but not in the sludge. Efficiency is calculated using the analytical detection limit of the pollutant in sludge.

REFERENCES

1. White, M. and G. Beluzo, GCA Corporation, *Performance Tests and Material Balance for a Fluidized-Bed Sludge Incinerator*, November, 1980.
2. Wall, H. and J. Ferrel, Municipal Environmental Research Laboratory, U.S. EPA, "Particulate Emissions from Municipal Wastewater Sludge Incinerators," Presented at Mid-Atlantic States Section, Air Pollution Control Association, Newark, N.J., April 27, 1979.
3. Copeland, B.J., "A Study of Heavy Metal Emissions from Fluidized Bed Incinerators," Proceedings of the 30th Industrial Waste Conference, May 6, 7, and 8, 1975. Ann Arbor Science, pp. 78-79, 1977.
4. Greenberg, R.R., W.H. Zeller, and G.E. Gordon, "Atmospheric Emissions of Elements of Particles from the Parkway Sewage Sludge Incinerator." Environmental Science and Technology. 15.64 (1981).
5. Bennet, R.L., K.T. Knapp, and D.L. Duke, "Chemical and Physical Characterization of Municipal Sludge Incinerator Emissions," NTIS No. PB 84-169325, March 1984.
6. U.S. EPA, Sewage Sludge Incineration, EPA R-2-77-040, August 1972.
7. Dewling, R.T., R.M. Manganelli, and G.T. Bear, Fate and Behavior of Selected Heavy Metals in Incinerated Sludge, Journal Water Pollution Control Federation 52(10), 2552-2557.
8. Adams, R.C., L.E. Keller, and E.V. Robb, Radian Corporation, "Particulate Removal Capability of a Baghouse Filter on the Exhaust of a Multiple Hearth Furnace Burning Sewage Sludge," Draft, September 30, 1985. EPA WERL, EPA No. 68-03-3148.
9. Adams, R.C., G. Bockol, J.A. Maddox, and E.V. Robb, Radian Corporation, "Particulate Removal Evaluation of a Electrostatic Precipitator Dust Removal System Installed on a Multiple Hearth Incinerator Burning Sewage Sludge," Draft, U.S. EPA WERL, September 30, 1985, EPA No. 68-03-3148.
10. Klinger, W.A., TRC Environmental Consultants, Biological Sludge Incinerator Air Impacts Study, Arlington County Department of Public Works, March 28, 1986.
11. U.S. EPA, Emission Measurement Branch, *Method Development and Testing for Chromium, Sewage Sludge Incinerator No. 13*, Detroit Water and Sewer Department, Detroit, MI, August 1986.